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LOCAL ENERGY TRANSFER TO TLDS BY NEUTRONS AND PHOTONS

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LOCAL ENERGY TRANSFER TO TLDS BY NEUTRONS AND PHOTONS*

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The local energy transferred from neutrons and photons to TLD materials with respect to energy transferred to biological tissues or air has been calculated. Experimental response of TLDs was measured for photons with energies above 1.5 keV.

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1. Introduction

A detailed understanding of energy transfer from neutron and photon fields to various thermoluminescence dosimeter (TLD) materials with respect to tissue, water and air is exceedingly important in certain energy regions if these materials are to be properly used for radiation dosimetry. We have computed the mean local energy transferred per unit path length and the energy imparted, within equivalent masses, to TLDs, tissue, water, and air. The ratio of these values are plotted for neutron energies from 10^{-9} to 20 MeV and for photons with energies from 10^{-3} to 20 MeV. The measured response is compared with the computed response at photon energies above 1.5 keV. All calculations were carried out using the Livermore Evaluated Nuclear Data Libraries (ENDL).

2. Theory

The mean local energy transfer in each energy group (E_g) per neutron collision is defined as

$$\bar{E}_t^n(E_g) = \frac{\Sigma_L f_L \Sigma_J \Sigma_I \sigma_{LJ}(E_g) E_{LJI}(E_g)}{\Sigma_L \Sigma_L f_J \sigma_{LJ}(E_g)} \qquad (1)$$

where f_L is the atom fraction of $\underline{L}^{th}$ element in the material, $\sigma_{LJ}(E_g)$ is the cross section for the $\underline{J}^{th}$ reaction at neutron energy (E_g) for the $\underline{L}^{th}$ element, $E_{LJI}(E_g)$ is the energy transferred to the kinetic energy of the $\underline{J}^{th}$ charged particle in $\underline{I}^{th}$ collision.

In ENDL evaluations, the average energy of the final-state neutrons is taken either from the kinematics of a two-body reaction with a defined Q-value or from tabular representations. The average energy of the final-state charged particles is either taken from the experimentally tabulated data or is estimated to equal x times the square root of the energy that is available after the average neutron energy has been removed, where x is 0.5 for $Z \geq 29$, 0.25 for $7 < Z < 29$, and 1 for $Z \leq 7$.

Similarly, the mean local energy transfer per photon collision is defined as

$$\bar{E}_t^p(E) = \frac{\Sigma_L f_L \Sigma_J \sigma_{LJ}(E) E_{LJ}(E)}{\Sigma_L f_L \Sigma_J \sigma_{LJ}(E)} \quad (2)$$

where $E_{LJ}(E)$ is the average energy transfer for the $\underline{J}^{th}$ reaction of $\underline{L}^{th}$ element. All relevant atomic reactions were included.

The ratio of energy transferred per unit path length of material N to material M is defined as

$$R_t^n(E_g)_M^N = \frac{\bar{E}_t^n(E_g)_N \; / \; (\rho_N dl)}{\bar{E}_t^n(E_g)_M \; / \; (\rho_M dl)} \quad \text{, and} \quad (3)$$

$$R_t^p(E)_M^N = \frac{\bar{E}_t^p(E)_N \; / \; (\rho_N dl)}{\bar{E}_t^p(E)_M \; / \; (\rho_M dl)} \quad (4)$$

for neutrons and photons, respectively, where ρ_N and ρ_M are the density of materials M and N, respectively.

3. Experiment

The experimental response of TLDs (ribbon 0.318 cm X 0.318 cm X 0.089 cm) was determined for photon energies above 1.5 keV. Monoenergetic photon beams were obtained using appropriate anode and filter materials. The TLDs were exposed under vacuum at photon energies below 10 keV. Photon flux densities were monitored using liquid nitrogen cooled windowless Si(Li) and NaI($T\ell$) detectors. The gamma spectra were unfolded using computer codes developed at Livermore.

4. Results

The results obtained using eqs. (3) and (4) for $R_t^n(E_g)_M^N$ and $R_t^p(E)_M^N$ are shown in figs. 1(a) and 2(a). The $R_t^n(E_g)_{tissue}^N$ for fast neutrons is less than one, as previously reported by Spurney et al.[1)] The experimental response on local energy transferred to TLDs with respect to air is shown in fig. 2(b).

Since the range of neutrons and photons at certain energy regions is less than the thickness of the TLD materials, the energy imparted within TLDs masses becomes quite important. The TLDs used in this study were 0.089 cm thick. The ratios of energy imparted within equivalent masses to TLDs, water, and air or tissue by neutrons with respect to tissue $R_i^n(E_g)_{tissue}^N$ are shown in fig. 1(b) and by photons with respect to air $R_i^p(E)_{air}^N$ are shown in fig. 2(b). Energy imparted to transferred quotient for air is shown in fig. 2(b). This demonstrates that the TLDs experimental response compares satisfactorily with theoretical values when TLD masses are taken into account precisely.

5. Conclusions

Knowledge of the local energy transfer and energy imparted in TLDs, water, air, and tissue by neutrons and photons is valuable in that it gives information on the overall problem of radiation dosimetry when determining the biological dose. Based on the results of this study, the neutron biological dose should be evaluated using methods other than TLDs, if possible.

The results presented in this paper demonstrate that when the energy imparted values are used the response of LiF dosimeters is quite good at photon energies above 2 keV. Otherwise, at photon energies below 10 keV, the biological dose can be off by several orders of magnitude. The use of CaF_2:Mn for determining the photon biological dose should be limited to energies above 200 keV unless supplemented by other methods.

References

1.) F. Spurny, R. Medioni and G. Portal, Nucl. Instr. and Meth. 138 (1976) p. 165

Figure Captions

Fig. 1. In A are shown the ratios of neutron energy transferred to various materials with respect to tissue; in B are shown the ratios of neutron energy imparted to materials, equivalent masses of TLDs, with respect to tissue.

Fig. 2 In A are shown the ratios of photon energy transferred to various materials with respect to tissue. In B are shown the ratios of energy imparted to materials, TLD equivalent masses, with respect to air. The experimental data are based on local energy transferred values.

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FIG 1 A

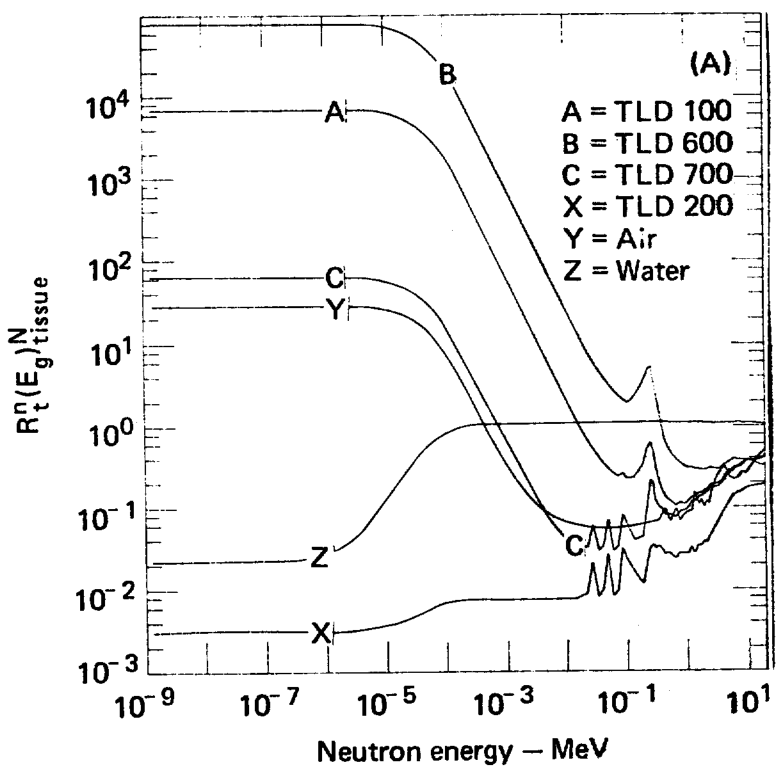
(A)
A = TLD 100
B = TLD 600
C = TLD 700
X = TLD 200
Y = Air
Z = Water
A
B
C
Y
Z
X
C
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-9}
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^1
$R_t^n(E_g)_{tissue}^N$
Neutron energy — MeV

Fig. 1(B)

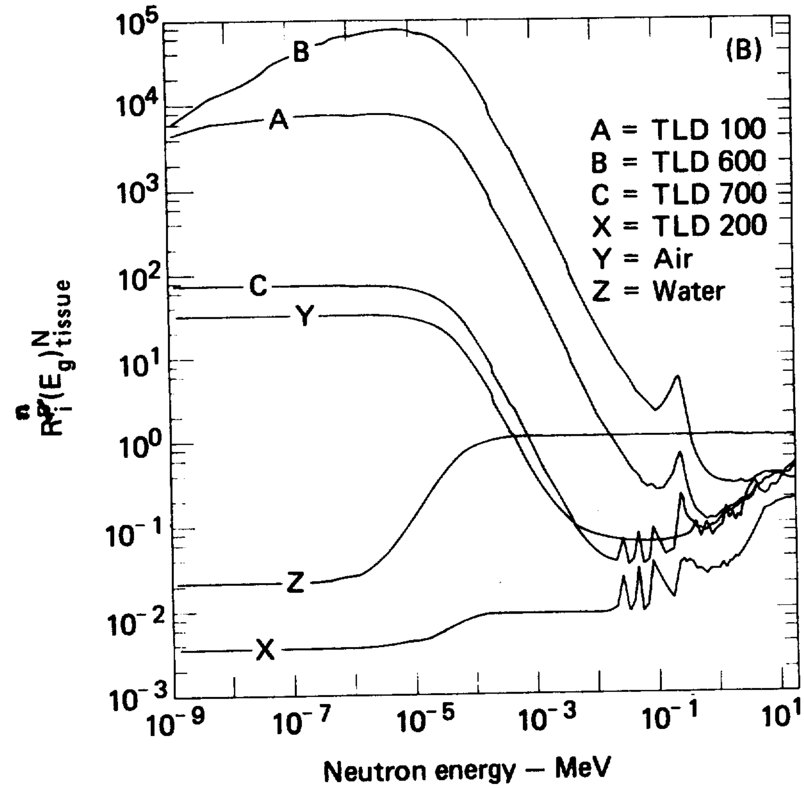
(B)
A = TLD 100
B = TLD 600
C = TLD 700
X = TLD 200
Y = Air
Z = Water
A
B
C
Y
Z
X
$R_i^n(E_g)^N_{tissue}$
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-9}
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^1
Neutron energy — MeV

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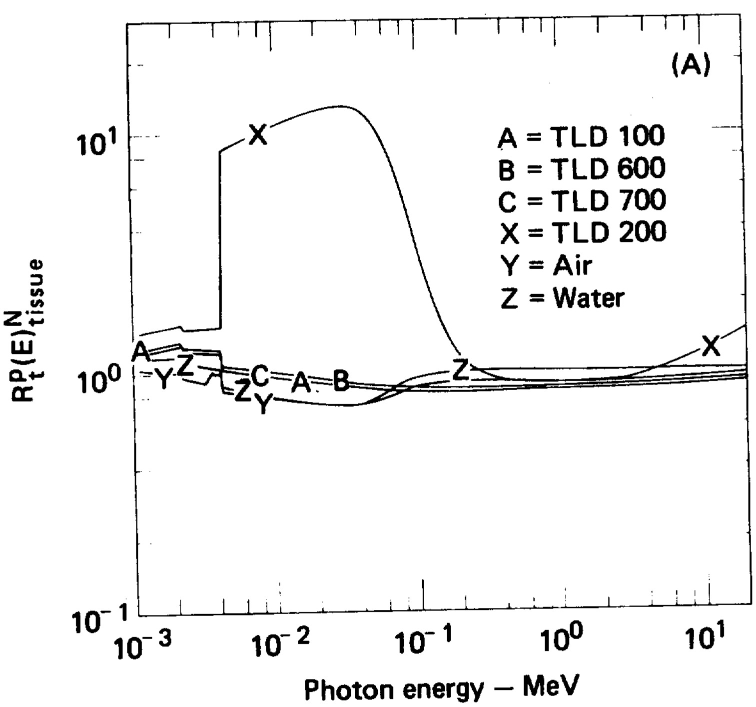
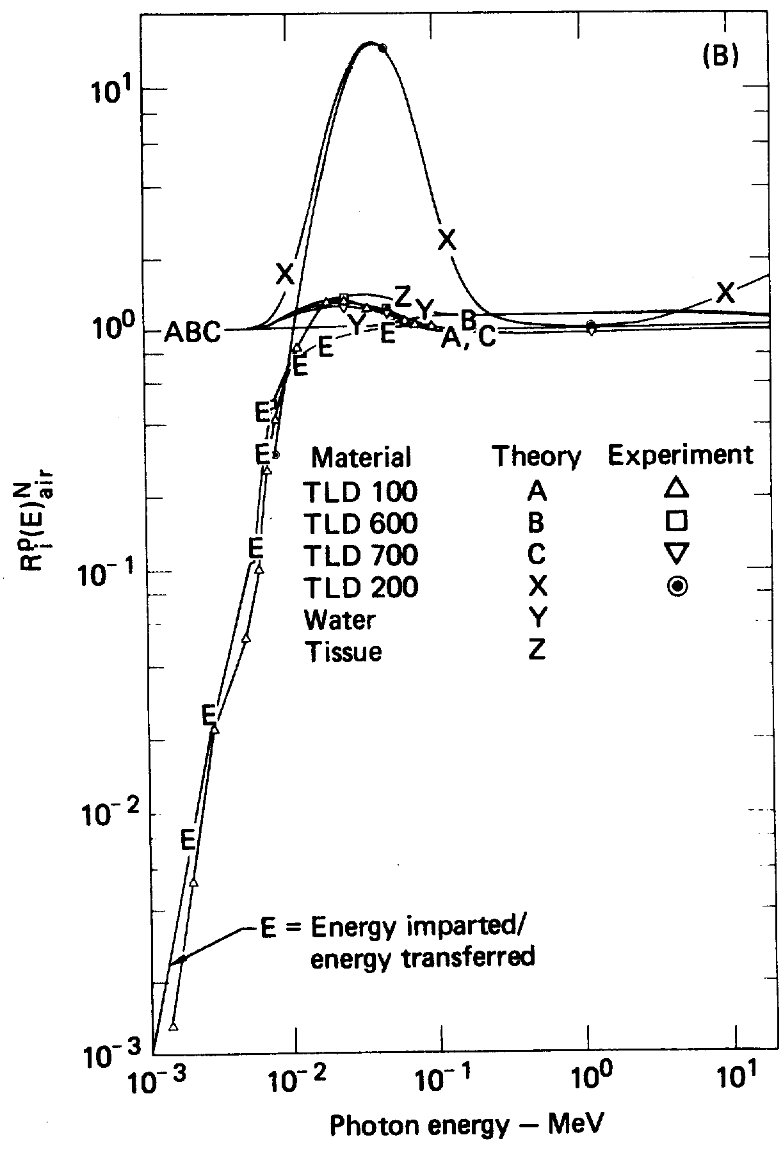
FIG 2(A)



(A)
A = TLD 100
B = TLD 600
C = TLD 700
X = TLD 200
Y = Air
Z = Water
$R_t^P(E)_{tissue}^N$
10^1
10^0
10^{-1}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
Photon energy — MeV

Fig. 2 (B)


(B)
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
$R_i^P(E)_{air}^N$
ABC
X
X
X
Z
Y
B
Y
E
A, C
E
E
E
E
E
E
E
E
Material
Theory
Experiment
TLD 100
A
TLD 600
B
TLD 700
C
TLD 200
X
Water
Y
Tissue
Z
E = Energy imparted/
energy transferred
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
Photon energy — MeV